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# Simulation Model for Sludge Thickener Performance in Municipal Wastewater Treatment Plants

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***Abstract***— *This paper covers the performance of the gravity thickener for Cairo wastewater treatment plants and determines the simulation model for it with different sludge types. A pilot unit erected in Zenin WWTP. The experimental results show that the performance of the thickener is varied periodically and its efficiency versus time relation can be simulated by several equations.*

*Efficiency equations simulate the performance by three equations due to the experimental work covered three intervals of retention time and affected by inlet sludge type. First equation simulates retention time from 0 to* 16 *hours, The second represent the period from* 16 *to 30 hours and the third covers the period from 30 to 40 hours. The produced efficiency by model equations achieved errors* $\pm$ *10% from the measured analysis that shows the applicability of the resulted model to use for such type of sludge treatment.*

***Keywords***— *Sludge thickening; gravity thickening; TSS; gravity thickening efficiency; retention time; thickening modeling; Municipal Wastewater Treatment; Sludge Treatment.*

## I. INTRODUCTION

With the high request in environmental pollution control, the importance of wastewater treatment became star subject. The disposal of treated wastewater and removed sludge were the main two items covered by researches to achieve the success of wastewater treatment in environmental pollution control.

The main sources of sludge in the municipal wastewater treatment plants are the primary sedimentation tank and the secondary sedimentation. Another type of sludge may also be acquired from chemical precipitation, nitrification – denitrification facilities, screening and filtration systems if the plant has these processes. Usually, the sludge resulting from these processes reused through the primary or secondary treatment systems so that the sludge mainly removed as either primary or secondary sludge. The resulting sludge from treating wastewater is composed of a large amount of water and concentration of solids. The sludge solids are composed of organic and inorganic matters. The solids largely contain matters responsible for pungent smell. The sludge treatment was very important to save its disposal or reuse. This was according to the high pollution in sludge chemically and bacteriology. This treatment controls the reuse or disposal methodology. Common sludge treatment processes include thickening, stabilization, dewatering, and disposal. Gravity thickeners are most commonly used in wastewater treatment plants in Egypt. Gravity thickeners are designed so as sedimentation happens due to physical reactions only, but what actually happens is that due to other incomprehensible reactions the sedimentation efficiency is affected. Several factors affect the sludge thickening, some of them are main and some minors due to the site conditions.

## II. EXPERIMENTAL WORK

A pilot plant was erected in Zenein WWTP in Cairo City. Zenein WWTP serves about 330000 $m^3$/day as average flow with about 15-20% industrial wastewater. The pilot unit was fed from the primary sludge, waste activated sludge and mixed sludge (40% PS + 60% WAS

Figure (1) shows the pilot plant system that consisted of the following components:

- 3 Plastic tanks with a volume 40 liters as feeding tanks for raw sludges.
- 3 Plastic hoses with 4 mm diameter as thickeners influent pipes.
- 3 Plastic tanks with a volume 20 liters as thickeners.
- 3 Plastic hoses with 4 mm diameter as thickeners effluent pipes.

The field experiment was operated on sludge with different retention times from (0 to 40 hour) for different sludge type. The pilot plant was operated in the same time with manual feeding for:

- Using the primary sludge only in one tank (40 liter) in upper (20 liter) in the lower.
- Using the waste activated sludge in one tank (40 liter) in upper & (20 liter) in the lower.
- Using the previous mixing mentioned (primary sludge & waste Activated sludge) in one tank (40 liter) in upper & 20 liter) in the lower.
- Using the first retention time = 12 hour with flow 1.67l/h consumes 20 liters and for 40 liters it took 24 hours retention time for the same flow.



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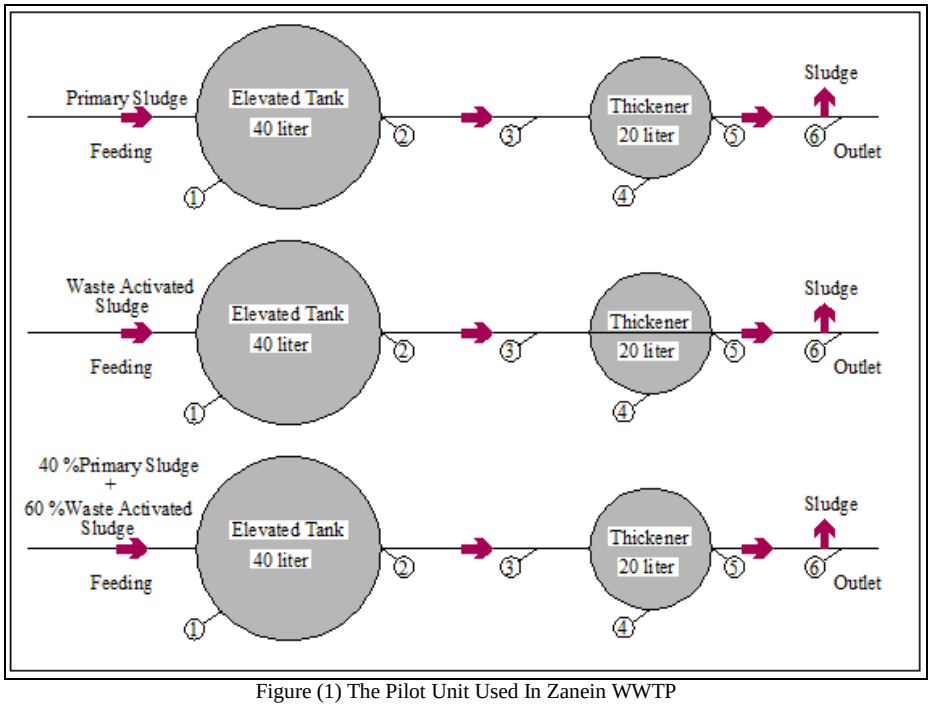


Figure (1) The Pilot Unit Used In Zanein WWTP

- At retention time = 12 hour , measuring of parameters (TSS) of the inlet sludge only one time in start and measuring of parameters (TSS) each 4 hours of along the experimental period of thickened sludge & measuring TSS at one time of the supernatant.
- Repeat the previous steps at the different rotation times (16 hr , 24 hr ,30 hr , 36 hr & 40 hour) with the different type of sludge (primary sludge, waste activated sludge & mixing sludge).

The measured parameters were TSS of inlet sludge, of thickened sludge. These analysis were run according to Standard Methods.

## III. RESULTS

Figs (1,2 &3) show the relation between efficiency and retention time during field experimental time.

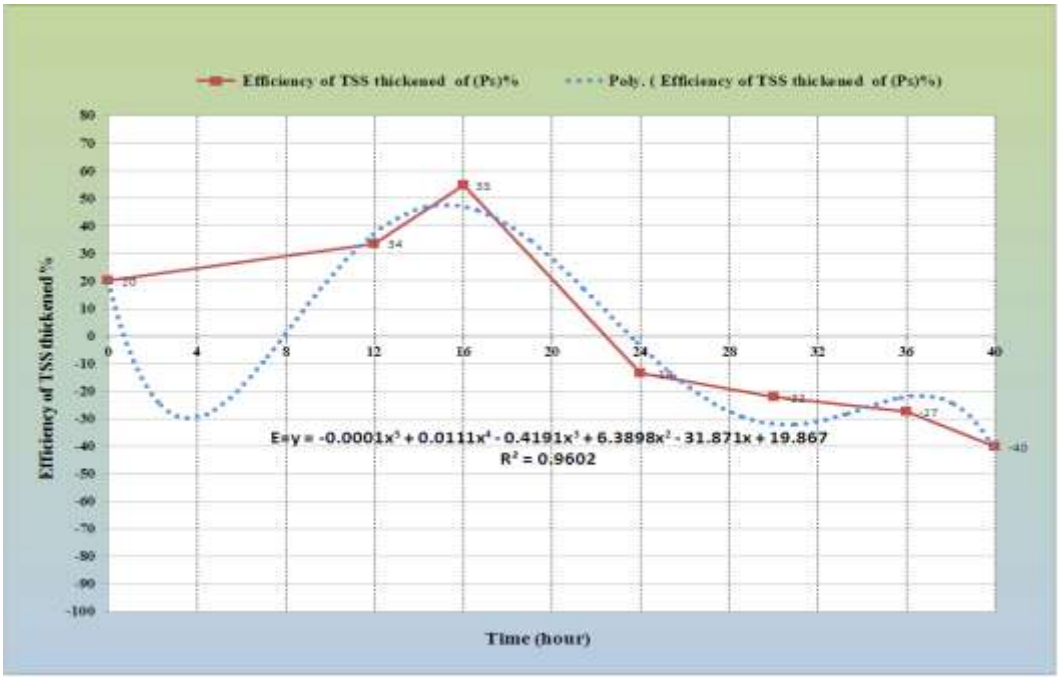


Fig (1) shows the relation between efficiency for primary sludge and retention time during field experimental



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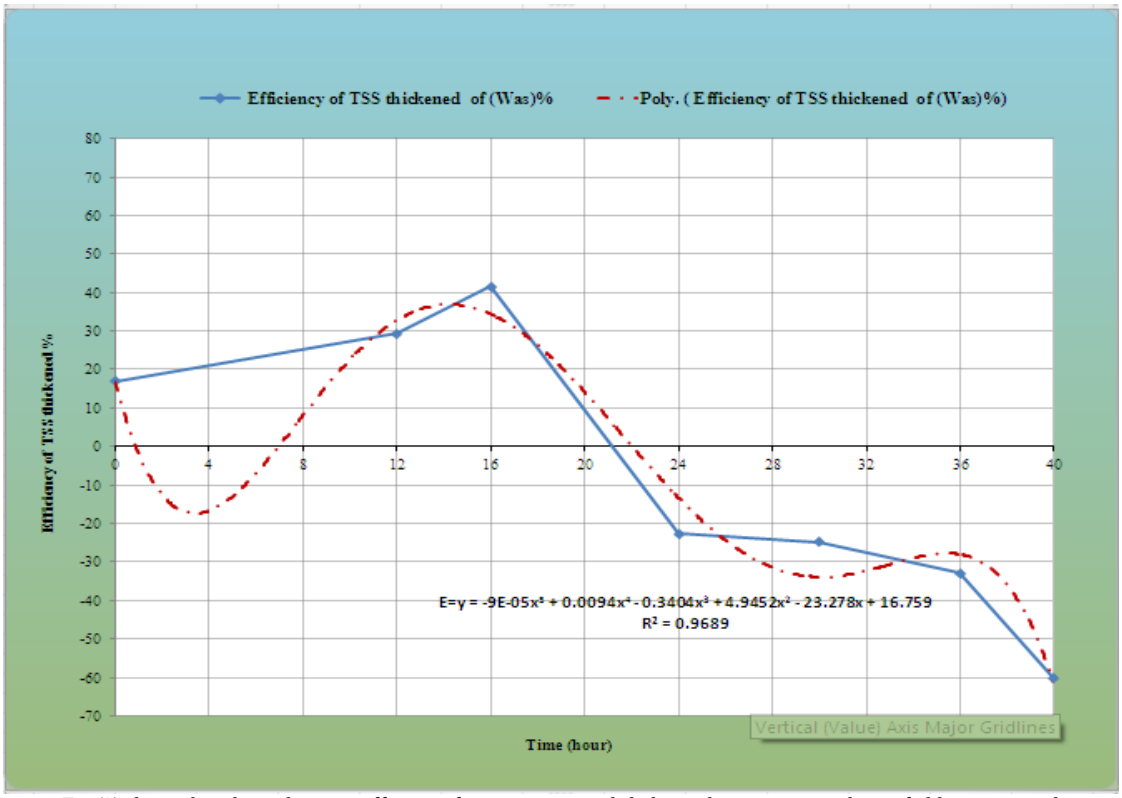


Fig (2) shows the relation between efficiency for waste activated sludge and retention time during field experimental


Figure (3) relation between efficiency for mixing sludge (40%ps+60%was) and retention time during field experimental

## IV. PRODUCED MODEL

The new model production was made by using the field experimental results and applying equation of mass balance of the gravity thickener. Figure (4) shows the flow diagram for producing model of thickening.



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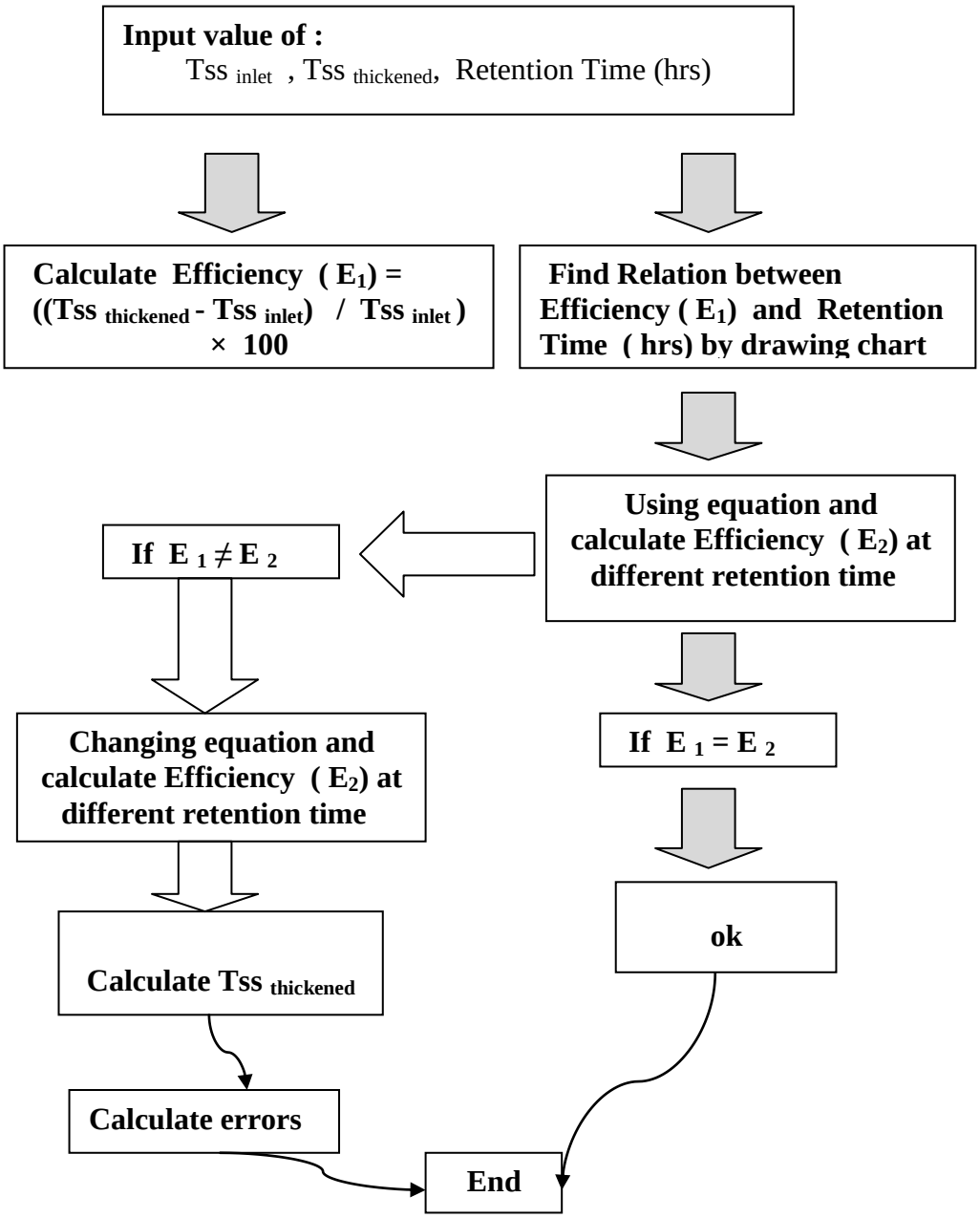


| | | |
|---|---|---|
| **TSS $_{inlet}$** | : | Total suspended solids of inlet sludge |
| **TSS $_{thickened}$** | : | Total suspended solids of thickened sludge |
| **$E_1$** | : | Efficiency during the field experimental results |
| **$E_2$** | : | Efficiency after modify equations |

Figure (4) Flow diagram for producing model of thickening

Table (1) shows the efficiency calculated for different sludge types at different times during field experimental when using equations in Figures (1, 2 & 3).

Table (1) shows (E measured ) for primary sludge is increase when the retention time increase up to 16 hrs, on the other wise, when retention time increase from (16 hrs to 40 hrs) find (E measured) for primary sludge turned negative signal. While (E calculated) increase when retention time increase from (0 hrs to 40 hrs) gradually increase more than 100% according the pervious table.

Also, (E measured) for waste activated sludge is increase when the retention time increase up to 16 hrs, on the other wise, when retention time increase from (16 hrs to 40 hrs) find (E measured ) for primary sludge turned negative signal. While (E calculated) increase when retention time increase from (0 hrs to 40 hrs) gradually increase more than 100% according the pervious table.



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Table (1) $E_{Measured}$% and $E_{Calculated}$%

| Sludge Type | PS(Primary Sludge) | | | | | | |
|---|---|---|---|---|---|---|---|
| Time (hrs) | 0 | 12 | **16** | 24 | 30 | 36 | 40 |
| $E_{measured}$ % | 20 | 34 | **55** | -14 | -22 | -27 | -40 |
| $E_{calculated}$% | 20 | 39 | **52** | 28 | 60 | 197 | 322 |
| **Sludge Type** | **WAS(Waste Activated Sludge)** | | | | | | |
| Time (hrs) | 0 | 12 | **16** | 24 | 30 | 36 | 40 |
| $E_{measured}$ % | 17 | 29 | **42** | -23 | -25 | -33 | -60 |
| $E_{calculated}$% | 17 | 34 | **38** | 3 | 5 | 52 | 60 |
| **Sludge Type** | **Mixed (40% PS + 60 % WAS)** | | | | | | |
| Time (hrs) | 0 | 12 | **16** | 24 | 30 | 36 | 40 |
| $E_{measured}$ % | 19 | 34 | **48** | -17 | -23 | -32 | -61 |
| $E_{calculated}$% | 19 | 37 | **38** | -32 | -108 | -220 | -394 |

For (E measured) & (E calculated) for mixed sludge are increase when the retention time increase up to 16 hrs, on the other wise, when retention time increase from (16 hrs to 40 hrs) find (E measured ) & (E calculated) for mixed sludge turned negative signal according the pervious table.

## V. Model Modifications

Producing model of thickening can be modifying as following by divided figures (5, 6 & 7) depended on retention time as following:

$E_1 = f(t)$ when $t = [0 \rightarrow 16]$

$E_2 = f(t)$ when $t = ]16 \rightarrow 30]$

$E_3 = f(t)$ when $t = ]30 \rightarrow 40]$

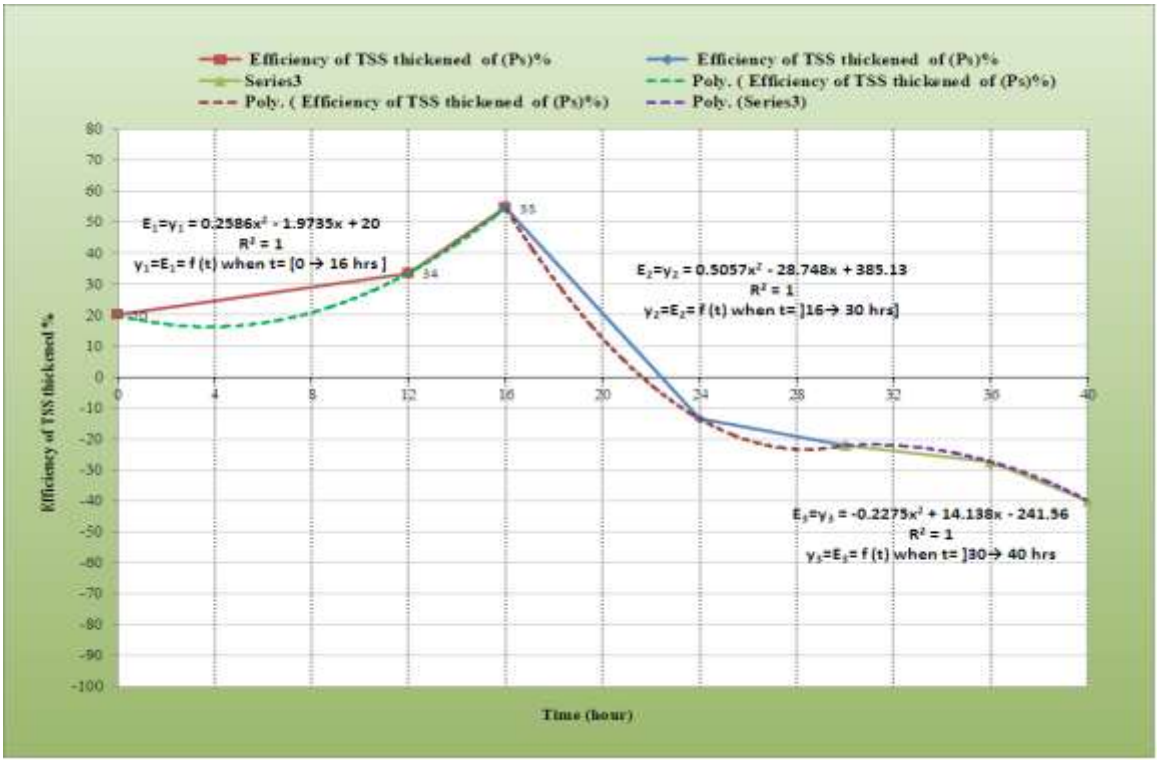


Fig (5) Relation between efficiency for primary sludge when divided retention time from (0 to 40 hours)



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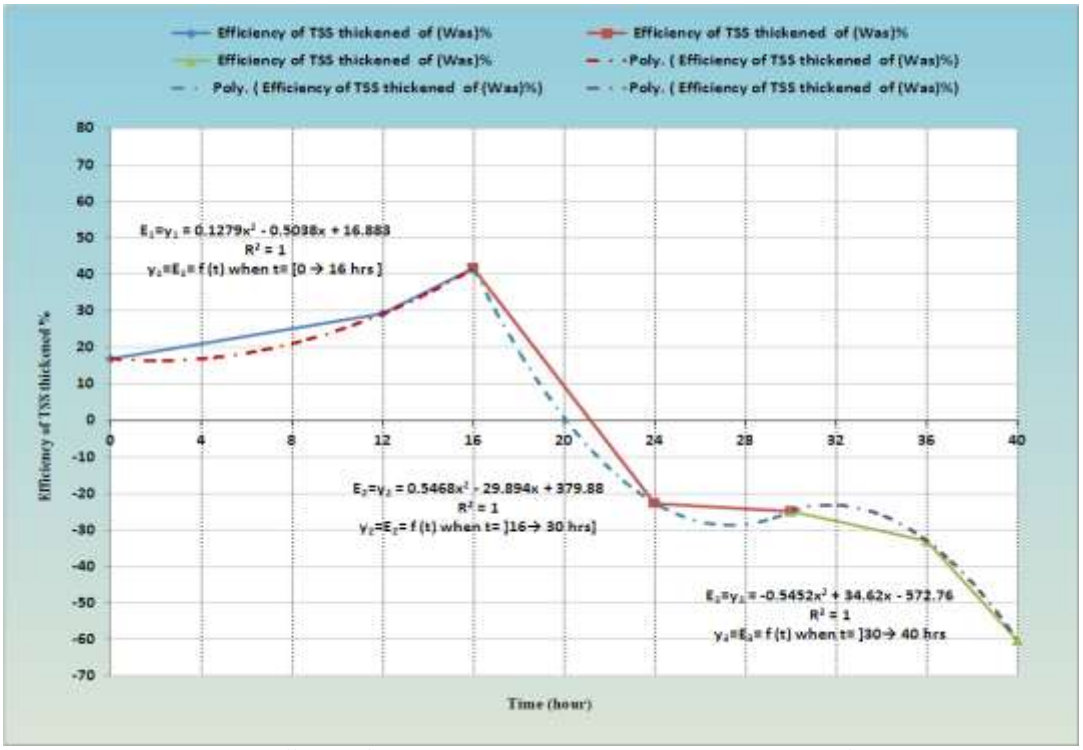


Fig (6) Relation between efficiency for waste activated sludge when divided Retention time from (0 to 40 hours)

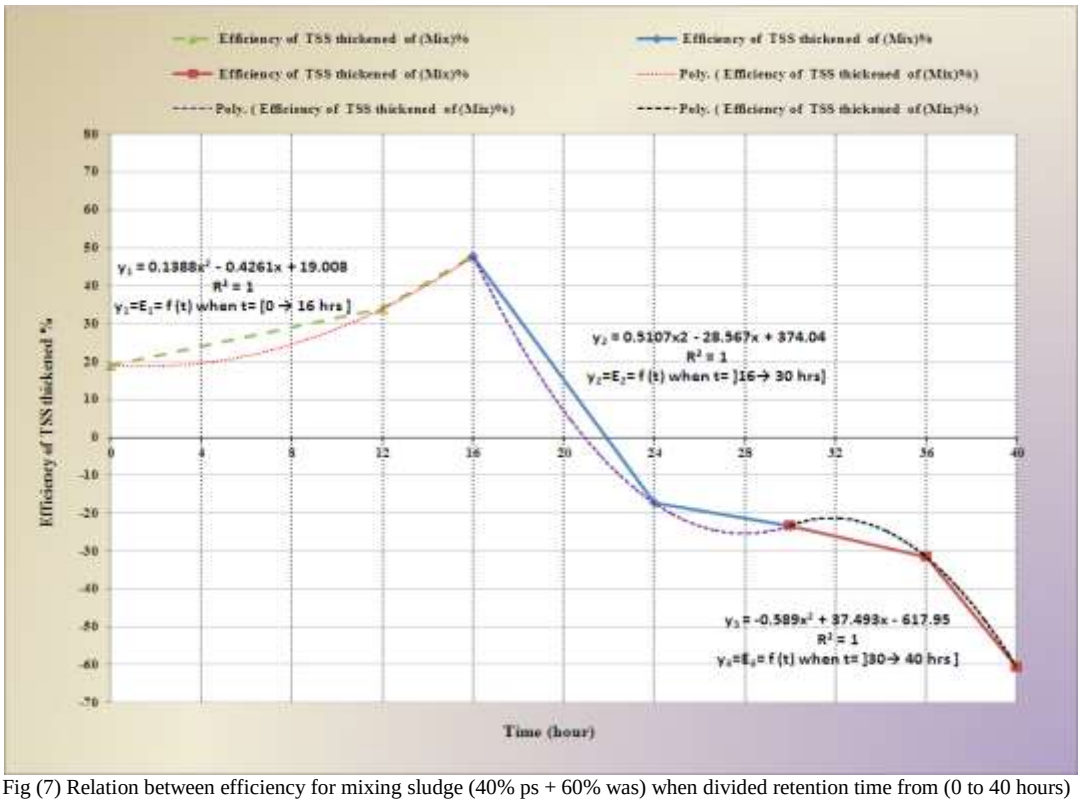


Fig (7) Relation between efficiency for mixing sludge (40% ps + 60% was) when divided retention time from (0 to 40 hours)

When using equations from previous table (2), the efficiency could be calculated at different retention time during field experimental for different sludge type as illustrated in table (3).

From previous table (3) due to the comparison between (E calculated %) and (E measured %) for all sludge types shows the result is the same. That means the modified efficiency equation simulates the real actual action that take place after efficiency equation modification find when retention time increase the efficiency value is the same value for (E calculated %) and (E measured %). Therefore, when TSS $_{\text{thickened}}$ is calculated by (E calculated %) is same value TSS $_{\text{thickened}}$ measured.



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Table (2) Efficiency Equations For Different Sludge Type With Retention Time From (0 To 40 Hours) According Figures (5, 6 & 7)

| Sludge type | Retention Time (hrs) | Efficiency Equations |
|---|---|---|
| Primary Sludge | t =[0→ 16 ] | $E_1 = y_1 = 0.2586\ x^2 - 1.9735x + 20$ |
| | t =[16 → 30 ] | $E_2 = y_2 = 0.5057x^2 - 28.748x + 385.13$ |
| | t =[30 → 40 ] | $E_3 = y_3 = -0.2275x^2 + 14.138x - 241.56$ |
| Where: x: Retention Time (hrs) , $R^2$= 1 | | |
| Waste Activated Sludge | t =[0→ 16 ] | $E_1 = y_1 = -0.1279x^2 - 0.5038x + 16.883$ |
| | t =[16 → 30 ] | $E_2 = y_2 = 0.5468x^2 - 29.894x + 379.88$ |
| | t =[30 → 40 ] | $E_3 = y_3 = -0.5452x^2 + 34.62x - 572.76$ |
| Where: x: Retention Time (hrs) , $R^2$= 1 | | |
| Mixed Sludge (40% PS + 60% WAS) | t =[0→ 16 ] | $E_1 = y_1 = 0.1388x^2 - .4261x + 19.008$ |
| | t =[16 → 30 ] | $E_2 = y_2 = 0.5107x^2 - 28.567x + 374.04$ |
| | t =[30 → 40 ] | $E_3 = y_3 = -0.589x^2 + 37.493x - 617.95$ |

Table (3) $E_{Measured}$% and $E_{Calculated}$ %

| Sludge Type | PS(Primary Sludge) | | | | | | |
|---|---|---|---|---|---|---|---|
| Time (hrs) | 0 | 12 | **16** | 24 | 30 | 36 | 40 |
| $E_{measured}$ % | 20 | 34 | **55** | -14 | -22 | -27 | -40 |
| $E_{calculated}$% | 20 | 34 | **55** | -14 | -22 | -27 | -40 |
| **Sludge Type** | **WAS(Waste Activated Sludge)** | | | | | | |
| Time (hrs) | 0 | 12 | **16** | 24 | 30 | 36 | 40 |
| $E_{measured}$ % | 17 | 29 | **42** | -23 | -25 | -33 | -60 |
| $E_{calculated}$% | 17 | 34 | **38** | -23 | -25 | -33 | -60 |
| **Sludge Type** | **Mixed (40% PS + 60 % WAS)** | | | | | | |
| Time (hrs) | 0 | 12 | **16** | 24 | 30 | 36 | 40 |
| $E_{measured}$ % | 19 | 34 | **48** | -17 | -23 | -32 | -61 |
| $E_{calculated}$% | 19 | 37 | **38** | -17 | -23 | -32 | -61 |

## VI. Model Verification

This check was made by applying Zenain waste water treatment plant experimental results in the produced model that resulted the efficiency that illustrated in tables (4, 5 & 6) as follows:

Table (4) $TSS_{thickened}$ measured at different retention time for Primary sludge.

| Type Of Sludge | PS ( Primary Sludge) | | | | | |
|---|---|---|---|---|---|---|
| Time ( hrs) | $TSS_{inlet}$ ( mg/l) | $TSS_{thickened\ sludge}$ measured (mg/l) | $E_{measured}$ % | $E_{calculated}$ % | $TSS_{thickened\ sludge}$ calculated (mg/l) | Error % |
| **0** | 10638 | 13150 | 24 | 20 | 12765 | -3 |
| **12** | 10638 | 14125 | 33 | 34 | 14253 | 1 |
| **16** | 10638 | 16285 | 53 | 55 | 16510 | 1 |
| **24** | 10638 | 9824 | -8 | -14 | 9197 | -6 |
| **30** | 10638 | 9249 | -13 | -22 | 8278 | -10 |
| **36** | 10638 | 8430 | -21 | -27 | 7719 | -8 |
| **40** | 10638 | 6500 | -39 | -40 | 6378 | -2 |

Table (5) $TSS_{thickened}$ measured at different retention time for Waste Activated Sludge.

| Type Of Sludge | WAS ( Waste Activated Sludge) | | | | | |
|---|---|---|---|---|---|---|
| Time ( hrs) | $TSS_{inlet}$ ( mg/l) | $TSS_{thickened\ sludge}$ measured (mg/l) | $E_{measured}$ % | $E_{calculated}$ % | $TSS_{thickened\ sludge}$ calculated (mg/l) | Error % |
| **0** | 8000 | 10000 | 25 | 17 | 9351 | -6 |
| **12** | 8000 | 10580 | 32 | 29 | 10340 | -2 |
| **16** | 8000 | 11750 | 47 | 42 | 11325 | -4 |
| **24** | 8000 | 6440 | -20 | -23 | 6190 | -4 |
| **30** | 8000 | 5843 | -27 | -25 | 6014 | 3 |
| **36** | 8000 | 5110 | -36 | -33 | 5358 | 5 |
| **40** | 8000 | 3250 | -59 | -60 | 3178 | -2 |

Table (6) $TSS_{thickened}$ measured at different retention time for Mixed sludge.

| Type Of Sludge | MIX ( 40% Primary Sludge + 60% Waste Activated Sludge) | | | | | |
|---|---|---|---|---|---|---|
| Time ( hrs) | $TSS_{inlet}$ ( mg/l) | $TSS_{thickened\ sludge}$ measured (mg/l) | $E_{measured}$ % | $E_{calculated}$ % | $TSS_{thickened\ sludge}$ calculated (mg/l) | Error % |
| **0** | 9185 | 12150 | 32 | 19 | 10931 | -10 |
| **12** | 9185 | 12728 | 39 | 34 | 12297 | -3 |
| **16** | 9185 | 13745 | 50 | 48 | 13568 | -1 |
| **24** | 9185 | 7750 | -16 | -17 | 7586 | -2 |
| **30** | 9185 | 7343 | -20 | -23 | 7041 | -4 |
| **36** | 9185 | 6610 | -28 | -32 | 6287 | -5 |
| **40** | 9185 | 3750 | -59 | -61 | 3616 | -4 |



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## VII. DISCUSSION

Discussing the previous tables (4, 5 & 6) the produced model application with Zenein WWTP measured data achieved accuracy error in the efficiency between ± 10% which is reasonable error for using such model for estimating the thickener performance and efficiency with Cairo Municipality WWTP.

The producing model results show the relationship between efficiency values and retention time's values during field experimental times for different sludge types. When substitution retention times from (0 to 40 hr) can be calculated the efficiency by different equations with the different sludge types. From a above we find that the gravity thickener does not work under one equation at different retention times (0 to 40 hr). Subsequently the need to use three equations to get efficiency values for different sludge types with retention times (0 to 40 hr) while using the gravity thickener is very important to get high accuracy in getting efficiency from the applied model. the first equation with retention times from (0 to 16 hr) for different sludge types, and the second equation retention times from (16 to 30 hr) for different sludge types, and the last equation retention times from (30 to 40 hr) for different sludge types. In this conditions with three equations ($R^2$=1) when $R^2$ (is the difference between a calculated value and measured value) when $R^2$=1, the result is very accurate.

Any physical action process; (sedimentation by gravity thickener) must be happening under one equation, but this is not the case in the study case in hand. That is reason of use the up mentioned three equations that acquired from the producing model.

From this, an illustration that there are other biological actions happened inside the tank beside the known physical action. The mentioned biological action due to anaerobic bacteria oxidizes organic matters in the complete absence of dissolved oxygen by utilizing bounded molecular oxygen in compounds such as nitrates ($NO_3$) and sulphates ($SO_4$) thereby decreasing them to stable matter along with evaluation of foal smelling gases like $H_2S$,$CH_4$.

There are other factors that affect the efficiency values of the gravity thickener like: types of sludge, age of the sludge, sludge temperature, PH, biological activity, retention times,……..etc.).

Finally, Gravity thickeners work with three equations according to the retention times. The first equation from retention times (0 to 16 hr), The second equation from retention time (16 to 30hr) , and the last equation from retention time (30 to 40 hr). When designing gravity thickeners, the effect of biological action happening after retention time 16 hr must be taken into consideration.

## VIII. CONCLUSIONS

The following conclusions can be apparently drawn regarding the stability of gravity thickener with different retention times for different sludge (primary sludge only, waste activated sludge only & mixing (40 % PS + 60 %WAS):

1. The results of this work simulates the all municipal wastewater treatment plants for cities whose industrial wastewater ratio is range from (15-25) %.
2. The produced model in this study could be benefit for designers for such type of wastewater plants to not increase the retention time of thickener than 16 hours or if they increase or the gentle mixing should be ensured made with suitable action.
3. Also the produced model could be useful for operators to determine the best time for thickening and the withdrawal of thickened sludge period.
4. The adaption of the mixed ratio of various sludge entering the gravity thickener represents one of a major parameters and factors that control the correct performance of the thickening process. This technique although conflicts the hydraulic load of the thickener should be applied for the correct performance of the thickening process. Accordingly, the hydraulic load of the thickener should be revised to comply with this technique.

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